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Inspec Abs C91043531 & Biryalcev et al, "STACS 91. 8th Ann.S ymp.Theoret.Aspects Comp.Sci",91,pp537-8 Inspec Abs C91030793 & You et al,"Proc.3rd Int.Conf.Industr& Eng.Appcns.AI&ES", 1990, v1, pp 357-364

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(54) Computer-aided geometry modelling

(57) A method for computer-aided geometry modelling makes possible a declarative, sequence-independent description of geometric shapes and features and allows an integrated modelling which combines the geometric relationships and connects them with non-geometric items of information. For this purpose, a representation of the geometry-related data takes place in the form of a representation element to which a density is allocated in the form of a real number. The interlinking of individual representation elements occurs through a single commutative and associative interlinking operation. A volume plane, a topology plane and a generic area and edge plane, which lies between these planes, are provided as description planes for the respective relevant items of information. Lying above these description planes is a feature plane on which features are defined and to which a knowledge-based system can refer.

FIG.2

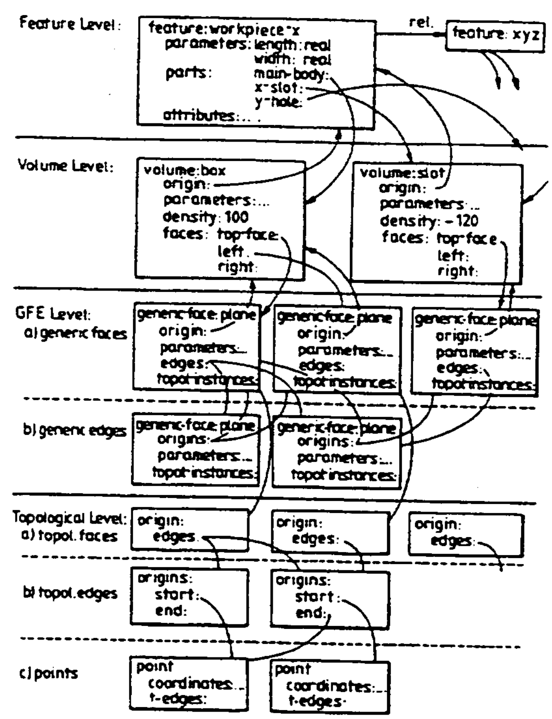

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FIG.1

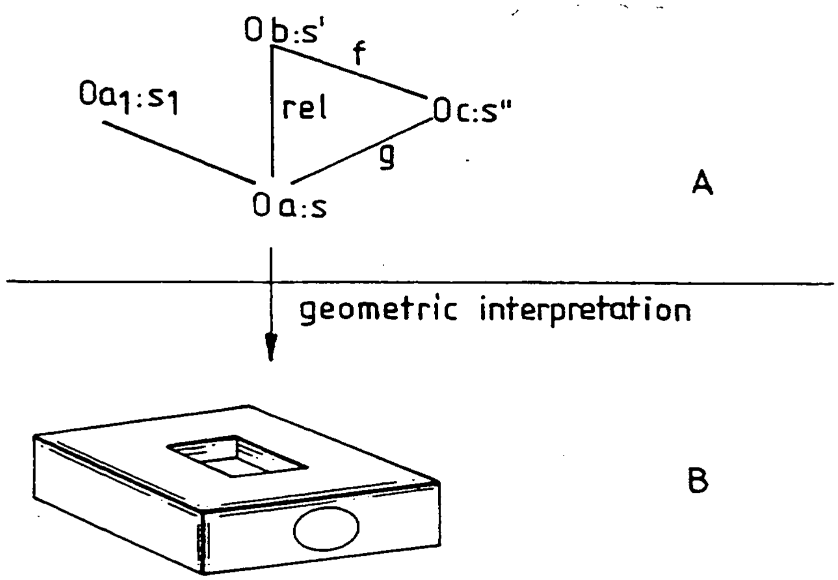


FIG.2

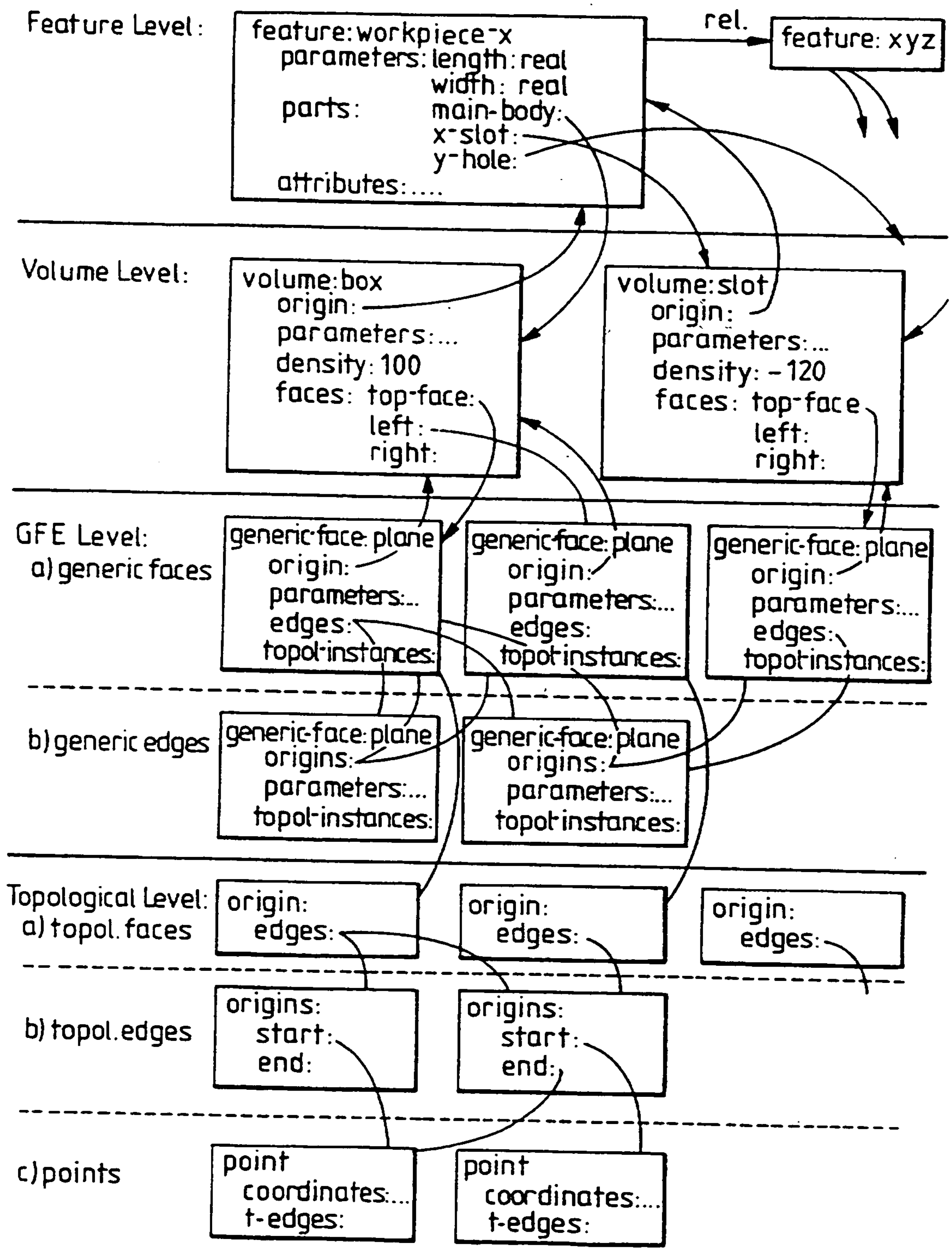
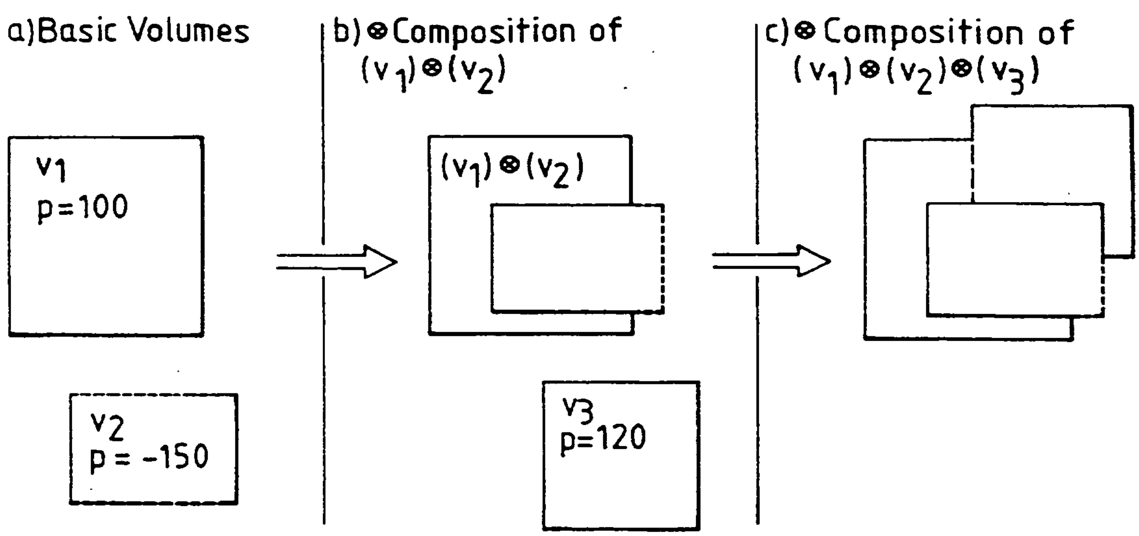

Feature Level:
feature: workpiece-x
parameters: length: real
width: real
parts: main-body:
x-slot:
y-hole:
attributes:....
rel.
feature: xyz
Volume Level:
volume: box
origin:
parameters:...
density: 100
faces: top-face:
left:
right:
volume: slot
origin:
parameters:...
density: -120
faces: top-face
left:
right:
GFE Level:
a) generic faces
generic-face: plane
origin:
parameters:...
edges:
topol-instances:
b) generic edges
generic-face: plane
origins:
parameters:...
topol-instances:
Topological Level:
a) topol. faces
origin:
edges:
b) topol. edges
origins:
start:
end:
c) points
point
coordinates:...
t-edges:

FIG.3



—— topological elements without material ("air")

---- topological elements within the material

—— "normal" topological element at the boundary between material and air

FIG.4a

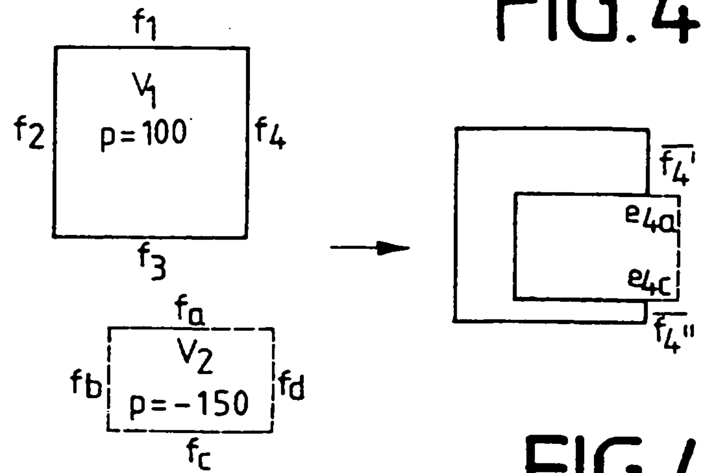


FIG.4b

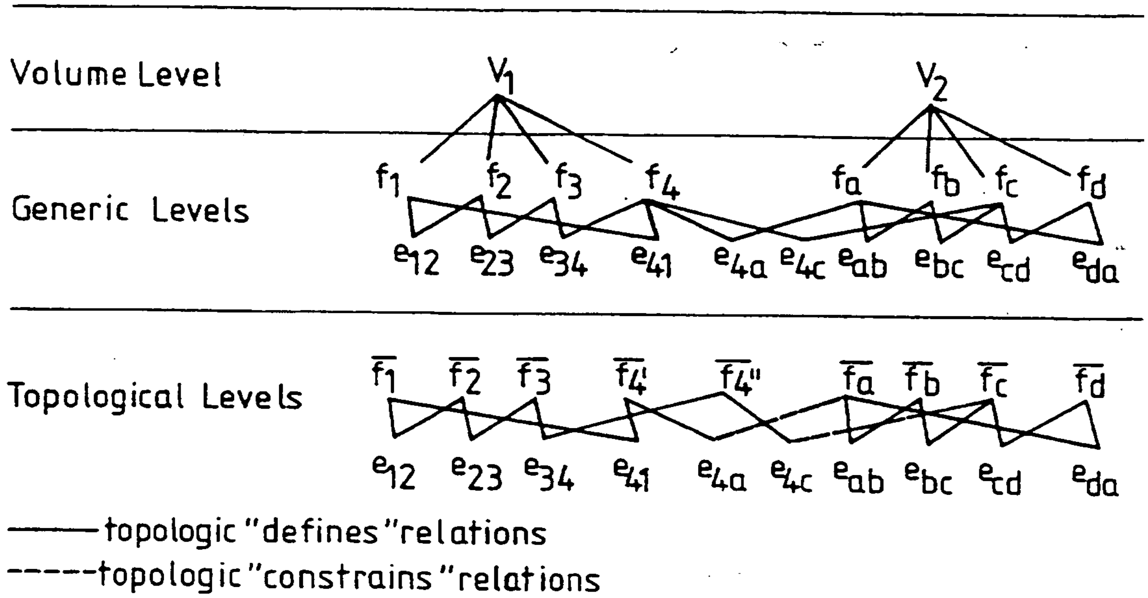


FIG.5

SOL = {...., b1:body,c1:cyl,c1.top=b1.face1,c1.bottom=b1.face2,...}

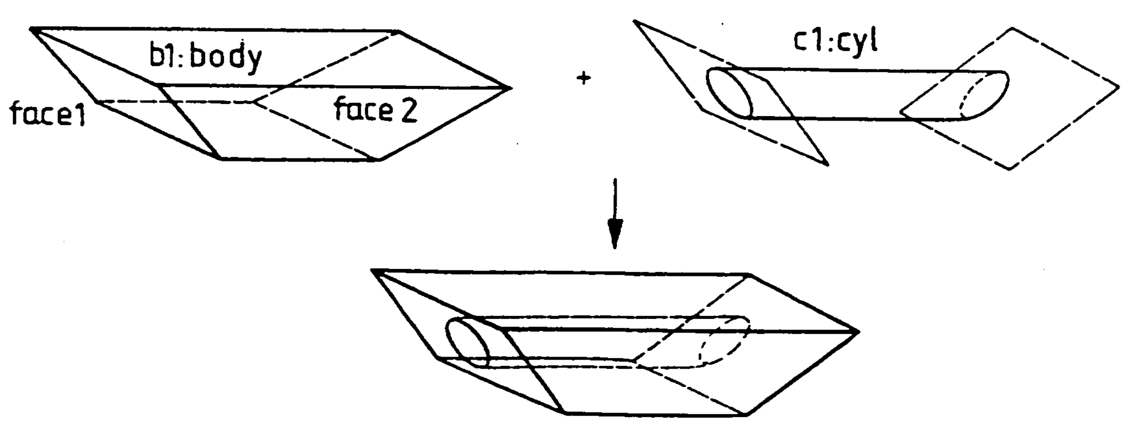


FIG.6

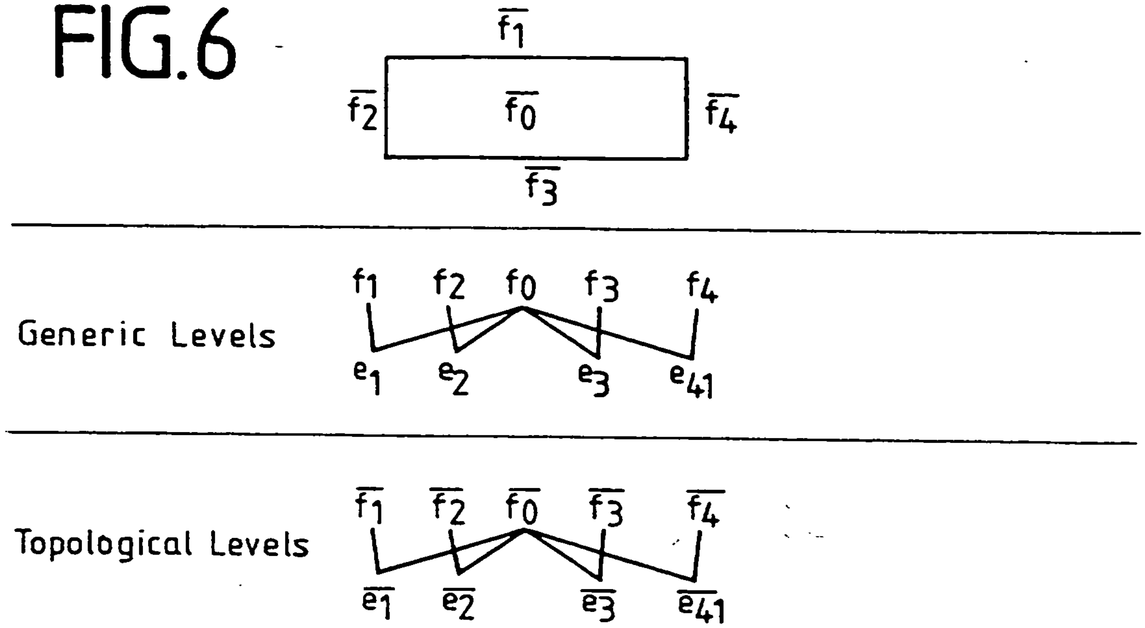
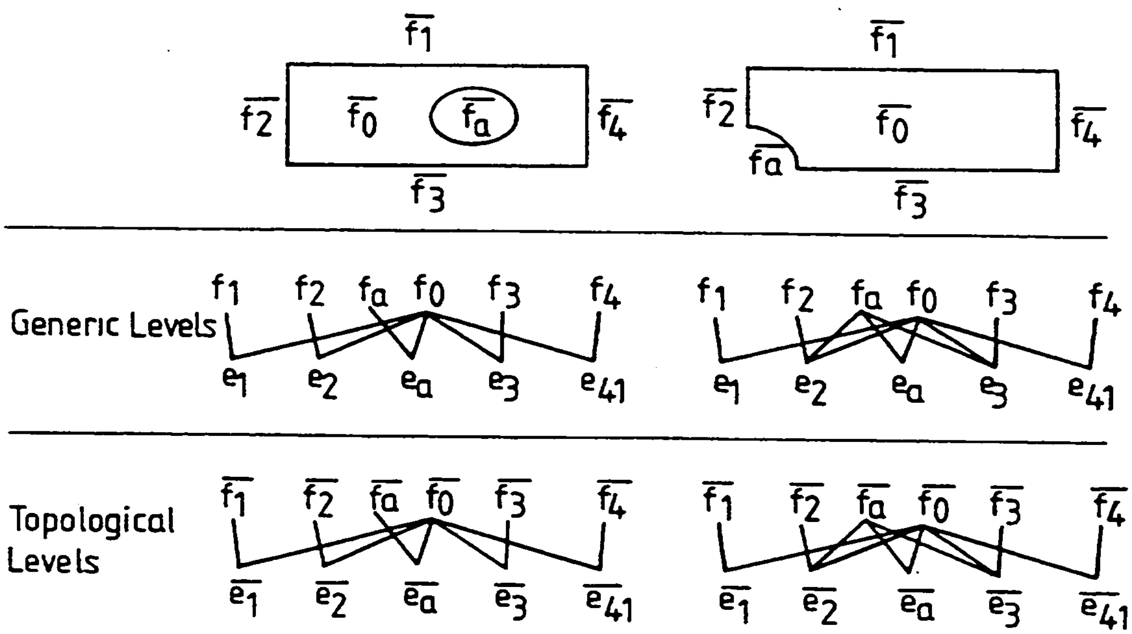

Generic Levels
Topological Levels

FIG.7


Generic Levels
Topological Levels

METHOD OF COMPUTER-AIDED GEOMETRY MODELLING

The present invention relates to a method of computer-aided geometry modelling.

Computer-aided geometry modelling in many applications makes high demands on the employed methods and algorithms. This applies for the description of regular geometries as well as also for free shape areas. At the same time, the close integration of the "naked" geometry description with other aspects such as functionality, material properties, tolerances and so forth is of great significance for many users. In order to do justice to this demand, concepts were developed in research as well as at many software supplier, with the aid of which concepts the required improvement in the possibilities of representation is to be achieved. A further increase in the performance capability of CAD/CAM systems and the geometry modelling contained therein is to be achieved by a close integration of geometry and knowledge processing (cf Krause et al), Feature Processing as Kernel for Integrated CAE Systems, IFIP International Conference, May 1994, Valenciennes). For this integration, information units (features) are a key concept: they represent a kind of bundling of geometry and geometry-related knowledge.

The CSG method (Constructive Solid Geometry), the B-Rep method (Boundary Representation) and different concepts of feature modelling (for example the EREP method (cf Hoffmann et al, "EREP - an Editable, High-Level Representation for Geometric Design and Analysis", Technical Report, Purdue University, West Lafayette, 1994) or E. Rieger "Semantikorientierte Features zur kontinuierlichen Unterstützung der Produktsgestaltung", Hanser Verlag, Munich, 1995) are known for geometry

modelling.

For the aspect of a knowledge-based system, the main problem in CGS modelling is the history-based (sequence-dependent) description of the geometry.

The boundary representation method is, due to missing information, only partially capable of integration into knowledge-based techniques. These items of information comprise topological and generic area-related information items and relationships between them, but not relationships with volumes and volume-related features.

The EREP method represents one of the most expressive feature concepts at present. It is based on the idea of presenting a representation of geometric shapes which exists independently of the "actual" geometry computation in a geometry model maker and can, for example, be edited. This is achieved by two central starting points:

- The presentation of a formal description language, in which the feature and thereby the geometry can be defined in a manner which is independent of a geometry model maker. This manner of representation is based on a sweep-oriented geometry modelling and features can be described by being set into "from-to" relationships with already existing features (more accurately their surfaces).
- In order to achieve the necessary flexibility of representation, the presence of special geometric relationships (constraint techniques) and degrees of freedom can be utilised in the geometry modelling in this known method.

In that case, there is the object of using independent possibilities of the geometry description and also the integration of constraint methods in the geometry modelling.

The feature modelling in the known method is based on a procedural mode of construction, whilst initially no attention is directed to the declarativity of the geometry representation. The integration of different aspects of geometric modelling, namely volume-related, area-relevant and topology-relevant information items in integrated manner and subject to consideration of treating mutual dependence is absent.

The afore-described feature concepts fulfill only a part of the demands which are to be made on integration with knowledge-processing systems. The significant weak points can be summarised as follows:

- The possibilities of expression are often too weak in the feature representations: they follow volume-oriented, area-oriented or sweep-oriented geometry representations and offer too few possibilities of representations for the respective other "manners of viewing". The possibilities of defining relations between different features and filling out features hierarchically are often only weak.
- Feature interactions cannot be described with the required force of expression. This applies, in particular, in draft-oriented feature concepts, but a greater degree of significance is usually attached to this aspect in conceptions for production feature.
- From the aspect of the knowledge representation, it is particularly problematic that previously a procedural consideration formed the basis of most feature concepts. They are more or less a kind of "macro", by which a predefined sequence of instructions to the geometry model maker can be summarised and activated.

For a feature concept which is to serve as a connection to knowledge representation, the question of the available possibilities of expression

and also a declarative description are significant. It is necessary to be able to describe adequately as far as possible all relationships in the geometry and between the geometry and other aspects, such as material, tolerances and so forth and it must be possible to do this in a declarative manner in which the significance of the description results from it itself, independently of the processing model forming the basis.

Previous kinds of geometry modelling do not allow these objects - possibilities of expression and declarativity - to be achieved to the required extent. The orientation to volume-oriented or area-oriented geometry description restricts the representation of relationships of the respective other "plane" and the sequential (sequence-based) form of modelling of geometric shapes prevents a declarative manner of consideration. This manner of procedure also conflicts with the required interactive mode of operation, in whch the constructor not only builds up geometry step by step but also rejects, revises, modifies it and so forth. Because of the hitherto constrained sequence-based manner of procedure, the constructor often carries out geometry operations which are somewhat intuitive: in order for a required revision of geometry to avoid a lengthy resetting of operations ("history") executed in the sequence, new geometry operations are added, which finally create the same overall geometry as the revision of earlier steps would have created, but are comprehensible in their significance only in this context.

In this case, the loss of information due to representation of the geometries of a boundary representation presents many problems, for example in obtaining of production-relevant representations (numerical control programming) from the geometry or in consideration of production

aspects during the design process (in the sense of a concurrent engineering).

There thus remains a need for an expressive and declarative description of geometric information units (features) and relationships for computer-aided geometric modelling of a workpiece. Information units in this case are such as may carry geometric and other ("semantic") information. The need is for an integrated, declarative, logic-oriented modelling of features and geometry, which in itself combines geometric relationships related to volume, areas, lines, points and topology and connects it with non-geometric information. A powerful interface between geometry modelling and knowledge processing is to be created.

According to the present invention there is provided a method of computer-aided geometry modelling of a workpiece, comprising the steps of providing an integrated, declarative, sequence-independent and logic-based representation of information relating to volume, areas, edges, point and topology in the form of a representation element composed of individual basic volumes, to each of which a respective density in the form of a positive, zero or negative real number is allocated, interlinking individual representation elements by a commutative and associative interlinking operation, and creating description planes for the respectively relevant information items and their mutual dependence in the form of a volume plane as base plane for the description of elemental structures fixedly preset in composition, a topology plane as representation of the overall geometry, and a generic area plane and a generic edge plane both lying between the volume plane and the topology plane for production of the relationship between the topological structures and the volumes generating those structures.

Previous feature concepts start out essentially from the previous kind of geometry modelling and impose on it a description plane, with the aid of which more complex geometric shapes ("geometric features") as well as relationships between geometry and other information ("semantic features") can be described. The possibilities of expression of the feature concept hitherto primarily depend on the possibilities of the respective geometry modelling. A method exemplifying the present invention follows the opposite path: the starting point for the conception is formed by the desired force of expression and the requirement for a declarative representation as central prerequisite for the integration of knowledge processing and geometry, i.e. the method serves for achievement of a powerful interface between geometry modelling and knowledge-processing system.

The feature representation in the method permits a plurality of different relationships (constraints) to be expressed, which are taken into consideration for derivation of the complete geometry information for the geometry modelling. The geometry modelling secures, by the special mode of operation, that the sequence in which the problem solver (knowledge-based system) "supplies" it with information plays no part in the resulting overall geometry.

It is ensured by the structure of planes that all relevant items of information can be represented where they have their place and all relationships between the different aspects of geometric modelling (volume, areas, parameters, topology) are components of the overall illustration and thus do not get lost. In this sense, the method is both a hybrid and an integrated modelling base. Due to the explicit representation of all relevant geometry information items, it is possible

to fully integrate these relationships during the knowledge processing and, for example, to use them as constraints for the corresponding "entities".

Examples of the present invention will now be described with reference to the accompanying drawings, in which:

Fig. 1 is a diagram showing a declarative feature and relation plane and its imaging on the geometry;

Fig. 2 is a diagram showing description planes in a method exemplifying the invention and their dependencies;

Fig. 3 is a diagram showing interlinking of three volumes in two steps in the method;

Fig. 4a is a diagram showing generic areas of the two two-dimensional "volumes" according to Fig. 3;

Fig. 4b is a diagram showing the description planes of the generic areas of Fig. 4a;

Fig. 5 is an illustration of a relationship between a certain basic volume and a cylinder which are correlated over two areas;

Fig. 6 is a generic and topological representation of a rectangle (without associated geometric constraints); and

Fig. 7 is a generic and topological representation of "non-rectangles" (without geometric constraints).

Referring now to the drawings, in order to meet the object of an expressive and declarative geometry and feature modelling which takes into account the special requirements of the knowledge processing, two questions are to be examined:

- Which kind of geometric and other information must be represented and in which structure?
- How must a geometric model maker and, in interplay therewith, a

knowledge-based problem solver look in order to achieve this kind of geometry description?

The solution presupposes that the geometric model maker itself is modified in a manner which secures its compatability with the feature modelling given by the method exemplifying the invention. These modifications consist on the one hand in a specific kind of the geometry representation: More geometric information must be stored and treated than in previous methods. On the other hand, a certain restriction of the geometric interlinking operations is required, which are possible on the geometric plane.

On the part of the problem solver, a powerful "constraint machine" is required above all, which makes certain that all information items, which are contained in a given representation, are (also implicitly) also actually available (i.e. are derived).

A knowledge-based problem solver - for example an intelligent design assistant who aids the constructor in the solution of design problems - must be capable of "extracting" knowledge from the geometry model (by retrieval, abstraction, classification and so forth) as well as also cause the geometry model maker to make certain changes in the geometry model (adding or substracting geometry, changing parameters, undertaking local geometry manipulations and so forth).

According to the concrete kind of the problem, for which the problem solver was designed, these interactions can be of different forms and ordered differently into the overall context. For design tasks, for example, the object typically consists in securing on the one hand that the previously generated (part) solution inclusive of geometry fulfills the preset objects and is consistent on the other hand (i.e. fulfills a quantity of constraints of different kind).

In the following, some of the core requirements are summarised,

which are made on the geometry model from the aspect of a knowledge-based system. In that case, technical details matter less than rather the quality of the requirements.

The knowledge, which the problem solver has about the generated (part) solution, can be represented in this in different forms. It will typically, however, comprise knowledge about objects (including geometric features) and about their properties and relationships including the geometric ones. This knowledge is representable, for example, in a predicate-logical or comparable language, in which inter alia the following relationships can be expressed:

- Objects are described by an identifier a, b, c (for example "hole 1" or "slot 2") and their belonging together to a sort s, s' (such as for example "through-hole" or "slot"), (in the form a:s, such as for example "hole 1":through-hole");
- attribute f, g (for example "length", "top-face") serve for the description of unambiguous (functional) relations between objects (as a.f = b) and
- desired relations rel (for example "connected", "on") between objects a and b can be represented in the form rel (a, b), for example "connected (hole 1, slot 2)").

For a given problem, a (part) solution SOL_i can then be represented as a quantity of expressions of that kind:

SOL_i = [hole 1:through-hole, slot 2:slot, hole 1.top-face = face 12, connected (hole 1, slot 2), ...]

With the aid of the generally valid knowledge available to the problem solver and the geometry model maker, the complete and also geometric description of this part solution is to be derivable from this description on the one hand and it is to be made certain that this solution is consistent, i.e. fulfills all requirements. (In that case, it is presupposed that all information items, which are required for the complete description of the geometry, are made available by the problem solver). In that case, the sequence in which the knowledge (the individual expressions) gets into the partial solution is not relevant for its significance and thereby for the interpretation of the partial solution SOL_i altogether.

In Fig. 1, the region A in this sense shows a declarative description of features and relations, which are translated - indicated by an arrow - by means of geometric interpretation into the geometric model shown in the region B.

Such a manner of procedure is not aided by hitherto developed geometry modelling methods: There, the overall geometry is dependent on the sequence, in which the individual partial geometries are interlinked one with the other.

For the interplay between knowledge-based problem solver and geometry model maker, two questions are important above all in the consideration of the required power of articulation:

1. Can one express all geometric relationships, which are important for the problem solver, in one feature concept? Are, for example, volume-oriented interlinkings as well as relationships related to areas, lines or points representable?

2. Has one the possibility of expressing generic knowledge about geometric shapes and relationships in the required generality, in particular also the "degrees of freedom", constraints and so forth, which are needed for this?

In view of the multiplicity of information items, which a geometry model maker has to manage, the question of the power of articulation is always also a question of practicability. It appears hardly realistic to make all information items, which are available to the geometry model maker, also accessible to the problem solver. It is therefore important for the interplay of knowledge-based system and geometry model maker to take the following into consideration:

- The possibilities of expression at the interface between both systems, i.e. in the case of the method exemplifying the invention, must be such that exactly those geometric relationships must be able to be described which are important for the problem solver. This applies also to those relationships, for which the geometry model maker is "responsible": Thus, for example, topological conditions which must be maintained or avoided. For this purpose, the geometry model maker must be capable of signalling those changes in the geometry, which result from a certain "action" of the problem solver and which are of interest to the problem solver, in targeted manner to the latter.
- In many applications, it is clear that not all that might be possible "in principle", for example geometrically, also actually happens. For reasons of efficiency, it should then be possible not to load the problem solvers with matters of that kind. Such "irrelevant" relationships are thus represented exclusively on the geometry plane and are not visible for the knowledge-based system.

Knowledge-based systems typically look for a solution. In that case, the solution is generated incrementally. Since control aspects are in that case already complicated enough anyway, it would be (or it is hitherto) a further complication when it is still to be observed during the generation of the individual partial solutions in which sequence these partial solutions are added to the overall solution. The overall solution is to be independent of the sequence, in which it was built up - an important aspect of the declarative knowledge representation considered here.

A further important point is the efficiency, with which the search can be performed in the normally very large search spaces. In that case, as intelligent as possible a manner of procedure is required, which is, for example,to include the consideration of dependencies in the search.

Often, the problem solver does not search on its own: It assists the constructor during his search for a solution. The constructor will thus, for example,want to retract decisions which were made at an earlier time and replace them by alternatives. For maintenance of the overall consistency, all conclusions must be reversed or computed anew on such a change.

With the aid of the general knowledge, a problem solver can derive a quantity of other statements from a partial solution SOL_i. By the addition of new knowledge to a next partial solution SOL_{i+1}, the quantity of the hitherto derivable ("valid") knowledge is, however, to remain maintained and additional knowledge can be obtained from the new plus the old information. This monotonic property is not always fulfilled, also in other fields of application. For example, in consequence of lack of concrete information, "first time" ascertained assumptions ("defaults")

are taken up into the solution, which later proved not to be correct (or not optimum) and are consequently revised. Consequently, statements, which are derived from these assumptions, drop out again. In order to be able to treat such problems correctly, special mechanisms, such as for example a dependency management, are required in problem solvers of that kind.

During the geometry modelling, however, still other factors arise, which finally likewise lead to non-monotonic modes of behaviour. By the addition of new partial geometries (of an operation which is actually monotonic in the sense of the knowledge representation), for example, the topology of the geometry model changes: areas which hitherto were contiguous are no longer such; intersections of straight lines which were hitherto contained in the model now drop out; a rectangle loses its geometric shape due to cutting-off or addition and thus goes over into another "area class"; and so forth. The question results from this whether geometric forms of representation can be found which assist in dealing with this specific kind of geometric non-monotony in the most favourable manner.

Apart from this kind of non-monotony which follows from the specifics of the geometry, it is important for many applications of knowledge-based techniques that they can be operated in an interactive manner in which the user (for example the constructor) engages in the problem solution. In that case, he makes not only decisions, he also revises previously made ones (for example, changes parameters or removes partial geometries again from the solution).

The geometry can be varied not only by the addition or removal of

partial geometries, but - insofar as the representation offers appropriate possibility - also by the changing of geometric parameters. Thereby, also other parameters connected by constraints are varied in some circumstances (constraint propagation). Thereby, also changes in the topology of the geometry can result.

The change in the structure of the geometry as well as also in the parameters require a dependency management, with the aid of which it can be illustrated which changes are required as the consequence of other changes, for securing the overall consistency.

This revisability inclusive of dependency management is an indispensable prerequisite for a full interactive mode of operation of the geometry model maker.

Previously, the most important demands, which must be made on a functionally capable feature concept in order that, in particular, it aids the interplay between a knowledge-based problem solver and a geometry model maker, were combined. This interplay is so intended that the knowledge-based component through logical inferences, constraint propagation and so forth prepares all information items which the geometry model maker needs in order therefrom to be able to generate a geometry representation (compare Fig. 1). The specifics of the method exemplifying the invention in that case consist above all in two points:

1. The feature representation permits a plurality of different relationships (constraints) to be expressed, which are taken into consideration during the derivation of the complete geometry information for the geometry model maker.

2. The geometry model maker secures by the special kind of its manner of operation that the sequence in which the problem solver

"supplies" it with information plays no part in the resultant overall geometry.

Before it is described later how the knowledge-based problem solver "processes" the feature modelling, it is now first explained how the geometry model maker assures both mentioned demands (possibilities of expression and independence of sequence).

In order to fulfill this demand, the method exemplifying the invention is based on three ideas:

Firstly, possibilities of description exist on different planes: For the method exemplifying the invention, geometric shapes and relationships can be described oriented by volume, areas, lines, point and topology as well as in their mutual dependence. Sweep representations and free-shape surfaces are likewise integrated. It is secured by this structure of planes that

a) all relevant information items are represented where they have their place and

b) all relationships between the different aspects of geometric modelling (volumes, areas, parameters, topology) are component of the overall representation, thus do not get lost.

Due to the explicit representation of all relevant geometry information items in the method exemplifying the invention, it is possible to fully integrate these relationships during the knowledge processing (and for example to use them as constraints for the corresponding "entities").

Furthermore, the securing of the declarativity of the representation is of special significance, in particular also for the interlinking of partial geometries. For this purpose, above all, the sequence dependence

of "classical" geometric interlinkings must be eliminated. This is achieved in that merely a single interlinking operation, denoted in the following by $\otimes$, which is commutative as well as associative, is introduced by the method exemplifying the invention. Each volume is allocated a positive or negative density and the interlinking of the volumes occurs according to the respective densities.

The central representation element in the method according to the invention is a body (solid) Γ. This is defined by the integrated representation of the geometric information item concerning it, i.e. related to volume, areas, edges, point and topology. A solid consists either of a basic volume V

$$\Gamma = V$$

or it arises as the result of the interlinking operation $\otimes$ of two solids Γ_1 and Γ_2:

in case

$$\Gamma_1 = \{V_1, V_2, \ldots, V_n\}$$
$$\Gamma_2 = \{V'_1, V'_2, \ldots, V'_m\}$$

then

$$\Gamma = \Gamma_1 \otimes \Gamma_2$$
$$= \{V_1, V_2, \ldots, V_n\} \cup \{V'_1, V'_1, V'_2, \ldots, V'_m\}.$$

To secure the independence of sequence, this interlinking operation is commutative and associative:

$$\Gamma_1 \otimes \Gamma_2 = \Gamma_2 \otimes \Gamma_1$$
$$(\Gamma_1 \otimes \Gamma_2) \otimes \Gamma_3 = \Gamma_1 \otimes (\Gamma_2 \otimes \Gamma_3).$$

The exact nature of this interlinking in order to achieve these objects is described further below.

The analog to the CSG combining operation is thus described as ⊗ interlinking of two positive or two negative volumes and the analog to the CSG difference formation is described as the ⊗ interlinking of a positive and a negative volume.

As third important step in the method exemplifyingthe invention, the possible explicit modelling of geometric information items relating to volume, areas, edges, point and topology in their mutual dependence permits manifold forms of constraints to be defined between these representations. Thereby, the feature concept gets a high power of expression in the method exemplifying the invention. In that case, the relevant relationships can be formulated in the structure of corresponding logic, topological and arithmetic (geometric) constraints on each of the description planes.

In the method exemplifying the invention, geometric shapes and relationships are described on three planes. These are:

a) the volume plane:

Geometry modelling here takes place primarily oriented to volume. These basic volumes can be elementary (sphere, cylinder, box and so forth as well as also be composed of other shapes, wherein - by contrast to the feature plane (still to be explained later) and to the solid - the manner of the composition is fixedly preset here and not variable in its internal structure. Basic volumes can, however, be defined flexibly on the feature plane with the use of different forms of constraints (see Fig. 2).

b) The generic plane:

On this plane, the generic areas and edges are described. It results from the interaction of the areas which are formed by the individual

volumes (within a volume as well as also between different volumes). The type and parameter information of the areas and edges belongs to this plane. The generic edges are the result of the interaction of areas of one or two volumes. Both aspects are significant for the adequate and efficient treatment of structural and parametric changes and for the representation of the corresponding dependencies.

The generic plane consists of two subplanes: The generic area plane and the generic edge plane. The sense of this plane consists above all in forming the interface between the volume description and the topology. Here, the geometric information about the individual topological "entities" is represented and the relationship is produced between these and the volumes generating them. There is an unambiguous association between the generic areas and the volumes "generating" them as well as the generic edges and the generic areas, from the section of which they arise. The other respectively present volumes, areas and so forth have no influence thereon by contrast to the topology which does not have this locality property. This distinction is important for the treatment of constraint and dependence.

On this plane, geometric constraints can be defined between generic areas in edges and arithmetic constraints between the parameters which characterise these objects. A special form of constraints consists in equality constraints which express that two corresponding objects have the same geometric shaping.

c) The topology plane:

The topology plane is the lowermost description plane in the method exemplifying the invention. In conjunction with the planes lying thereover, it represents the "actual" geometry. By contrast to the

generic plane, in which there are clear associations with the corresponding volumes, the topology is the result of all participating partial geometries. Each topological unit (with the exception of the points) has an unambiguous line to a corresponding unit on the generic plane which contains the associated geometric information. The topology plane is divided into three subplanes according to the dimension of the involved units: areas, edges and points. The connection between the elements on the individual subplanes forms a complete description of the topology.

In detail, the method exemplifying the invention offers the following possibilities of description on the individual planes:

The volume plane:

```
basic-volume: volume-type ;;; predefined basic volumes such as
                          ;;; box, sphere, cone, ..., or
                          ;;; user-defined
              origin      ;;; feature to which the basic volume belongs
              parameters  ;;; complete parameter quantity for the
                          ;;; description of the geometric shape
              density     ;;; real number indicating the "density" of the
                          ;;; volume
              surfaces    ;;; the quantity of the boundary surfaces
              attributes  ;;; semantic information
              constraints ;;; dependencies between different parameters,
                          ;;; surfaces and so forth.
```

The significance of the density is still explained in detail later. In order to achieve the required flexibility in the representation, it is

possible to define or overdefine the density of the basic volume in a feature.

The generic plane:

generic area plane:

```
generic-face: type          ;;; area type (plane, cylindrical envelope,
                            ;;; ...)
              origin        ;;; associated basic volume
              parameters    ;;; parameters required for the description
              edges         ;;; lines intersecting with other areas
  topological-instances     ;;; elements on the topology plane which belong
                            ;;; to the respective generic area
              attributes    ;;; semantic information
              constraints   ;;; dependencies between different parameters,
                            ;;; edges and so forth.
```

Areas of free shape can also be tied into the overall representation on this plane in that they are defined as parts of volumes like analytical areas.

generic edge plane:

```
generic-edge: type          ;;; edge type (straight line, circular line,
                            ;;; ...)
              origins       ;;; an ordered pair of generic areas, the
                            ;;; intersection of which is formed by this
                            ;;; generic edge
              parameters    ;;; geometric parameters
  topological-instances     ;;; a quantity of edge elements on the
                            ;;; topological plane, which belong to this
                            ;;; generic edge
```

attributes ;;; semantic information

constraints ;;; parameter dependencies

The topology plane:

The topology plane describes the topology of the overall geometry. The extensions which are introduced by comparison with the modelling known from the boundary representation relate above all to two different types of relationships between areas and edges as well as also between edges and points. In a boundary representation, there is only one kind of relationship each time (an edge is bounded topologically by two points, and an area is bounded topologically by a closed line of edges and thereby determined in their topological classifying). Both the types present in the method exemplifying the invention have the following significance: The one ("defines") corresponds to the version known from the boundary representation and the other ("constraints") signifies that, although a parameter dependence exists, it is not a topological one. By this modified representation of the topology, any additional information item can be represented which is necessary for obtaining a declarative geometry representation.

The topological area plane is described as:

topological face:

origin ;;; associated generic area

edges ;;; quantity of closed lines of topological

;;; edges of the type "defines"

con-edges ;;; quantity of "constraints" edges, which are

;;; determined by the area (without

;;; influencing the topology of this area)

attributes ;;; semantic information

The topological edge plane is described as:

topological edge:

origin	;;; associated generic edge
points	;;; pair of corner points which bound the
	;;; edge
constraints	;;; quantity of points which lie on the edge,
	;;; i.e. are co-determined by the edge
	;;; without bounding it topologically
attributes	;;; semantic information
local features	;;; local features such as roundings, bevels,
	;;; ...

The point relations are always of the type "defines".

The (topological) point plane is described as:

topological point:

co-ordinates	;;; the point co-ordinates
t-edges	;;; the quantity of topological edges, on which the
	;;; point lies (differentiated according to
	;;; "defines" and "constrains").

In the consistent representation in the method exemplifying the invention, the individual description planes are, of course, not independent of the other: The types and parameters of the generic areas are connected with those of the associated volumes and the types and parameters of the edges with those of the areas, by the section of which they arise, and so forth. This is evident from Fig. 2, in which the arrows indicate the interlinkings between the individual planes.

Whilst the sequence (and of course of the manner of the operation), in which the individual partial geometries (volumes) are interlinked one

with the other, in the modelling according to the state of the art decides how the resultant overall geometry appears, this is achieved in the method exemplifying the invention by each basic volume being allocated a certain density (in the form of a real number).

The significance of the density is explained easily:

1.) each point p in space has a density $\rho(p)$ in the form of a real number.
2.) $\rho(p) > 0$ signifies that "material" is present at this point p.
3.) $\rho(p) \leq 0$ signifies that no "material" is present at this point p.
4.) When a point p is not contained in any basic volume, it has (by definition) the density 0.
5.) When a point p is contained in several volumes V_1, V_2 to V_n with the associated densities ρ_1, ρ_2 to ρ_n, it has the density with the greatest absolute value:

$$\rho(p) = \max(|\rho_1|, |\rho_2|, \ldots, |\rho_n|)$$

Fig. 3 illustrates this idea for three basic volumes V_1 (density ρ = 100), V_2 (density ρ = -150) and V_3 (density ρ = 120) by an example (which is merely two-dimensional for a better understanding), wherein an interlinking of the volumes V_1 and V_2 takes place as first step. Thereafter, the interlinking with the basic volume V_3 is then undertaken. It is clear that the resultant solid is determined by the densities of the individual partial geometries and thus independent of the sequence of the interlinking operations, i.e. one gets to the same result in the method exemplifying the invention also when the interlinking of the basic volumes V_1 and V_3 takes place first and only then an interlinking with the basic volume V_2.

Each point thus has an unambiguously determined density. For the interlinking of two volumes, only the relationship between both the density values from which the density value of the resultant volume results is thus always of importance.

In order better to be able to formally describe the determination of the resultant density for the interlinking of different volumes, a relationship "superior" (abbreviated: sup) is expediently introduced between two respective volumes, here between V_1 and V_2:

sup (V_1, V_2) equivalent to $|\varrho(V_1)| > |\varrho(V_2)|$

A special case arises in the case of equal absolute values of both the densities: When both the densities have the same sign, no volume is superior over the other one. The interlinking takes place to a unitary volume with the density which both partial volumes have. If the signs are, however, opposite, then the negative shall by definition be superior to the positive partial volume. It thus "wins" over the positive one so that material is removed in the overlapping region of both volumes.

Fig. 4a describes, as example from Fig. 3, the generic "areas" of both the "volumes" V_1 and V_2 here given two-dimensionally and Fig. 4b shows corresponding description planes. For reasons of clarity, the descriptions between the generic and the topological elements are here not graphic, but indicated only by the nomination. The topological elements are overlined for distinction from the generic ones. The areas f_a and f_b intersect with the area f_4, from which the edges e_{4a} and e_{4c} arise anew as a result of the interlinking (generically as well as also topologically). Since the basic volume V_2 is superior to the basic volume V_1, the topological elements of the basic volume V_2 remain unchanged

in the interlinking. The areas f_a and f_b of the basic volume V_2 "constrain" merely the newly arising topological instances $\overline{f}_4$' and $\overline{f}_4$'' of the "inferior" and consequently sectioned area f_4 of the basic volume V_1.

From the definition of the geometry density, it becomes clear for which purpose the two kinds of topological relationships, which were explained further above, are needed: The solid Γ, which is formed of the $\otimes$ interlinking of two solids Γ_1 and Γ_2, is not an intrinsically homogeneous formation. It consists of regions of different density. These different regions must be represented in their topology: the regions themselves as well as also the relationships between neighbouring regions.

The interlinking of two solids signifies conceptionally that each basic volume of the one solid interacts with each of the other solid. This interaction can appear such that there is no overlapping. If there is however such, then in the case of the interlinking of two basic volumes of different density, that one "wins" which is superior to the other one, i.e. it also remains unchanged in its topology in the interlinking operation with the other volume; merely the weaker volume is "cut into" and thereby changed in its topology. At the same time, the topology of the volume cut into is determined by the stronger volume so that a representation of this interacting dependency by "constraints" relationships is necessary.

Since each area is unambiguously associated with a volume, it is always to be decided unambiguously which density is present on each side of the area and at the intersecting edges of different areas for the interlinking of different volumes. Since the superior relationship is dependent merely on the absolute values of the densities, the resultant

topology also contains elements which circumscribe the volumes of negative density (as indicated in Fig. 3). In the case of the detail modelling, according to the example from Fig. 4b, from the volume planes by way of the generic planes to the topology, it becomes clear how the topology of the overall geometry changes by the addition of the basic volume V_2: Whilst the topology of the "weaker" basic volume V_1 is modified (inter alia by division of the topological area $\overline{f}_4$ into the parts $\overline{f_4}'$ and $\overline{f_4}''$), the topology of the basic volume V_2 remains maintained. The topological areas $\overline{f}_a$ and $\overline{f}_c$ belonging to the basic volume V_2 in that case "hang" partially in the air and the topological edges $\overline{e}_{ad}$ and $\overline{e}_{cd}$ as well as the topological area $\overline{f}_d$ "hang" in the air completely. Through this information, which is additional by comparison with the modelling in the case of the boundary representation, the prerequisites are created for further interlinkings independently of the sequence.

In the case of the method exemplifying the invention, the feature plane represents the uppermost description plane on which the description possibilities required for the knowledge-based problem solver are available: Objects (and thus also geometric features), their attributes as well as also relationships and constraints between these objects can be represented. Attribute values can inter alia be geometric shapes of any desired dimension. Between different geometric attributes (volume, areas, parameters and so forth), constraints describing the relationships on the other planes can be described independently of the kind of the attribute. With the aid of attributes, semantic information data can be connected with geometry.

The feature plane describes the following possibilities of description:

```
feature: feature type           ;;; can be defined by the user
         feature parameters     ;;; for the description of required
                                ;;; parameters
         parts                  ;;; description of the structure of the
                                ;;; features by elementary features or
                                ;;; basic volumes
         feature attributes     ;;; semantic information
         constraints            ;;; dependencies between different
                                ;;; attributes, "parts" and so forth.
```

The user-defined relationships offer the possibility of describing diverse relationships between partial geometries as component of the interface from the geometry modelling to the knowledge representation.

Fig. 5 shows a representation according to the method of a relationship between a basic volume "b1" of the type "body" and a cylinder "c1", which are correlated by way of the body surfaces "face 1" and "face 2".

As example, a workpiece "workpiece-x" as feature can,for example, be described as following:

```
feature:  workpiece-x
          feature-parameters: length, width, height
          parts:              main body: box,
                              x-slot: slot,
                              y-hole: cylinder-hole
          attributes:         material: aluminium 100,
                              manufactured: machine type xyz
          constraints:        x-slot.dir = main body.dir,
                              y-hole.dir = main body.
                              dir + 90, ...;
```

with the significance that this workpiece has a geometric shape which is composed of a parallelepipedonal basic body and has an insection therein in x direction and a cylindrical hole in y direction. (For reasons of transparency, the constraints which express the geometric relationships between these features are not also illustrated). The sorts 'box', 'slot' and 'cylinder hole' are basic volumes with corresponding densities. The indicated attributes illustrate the integration of semantic information with the geometry. The constraints illustrate merely by way of detail the relationships which apply between the different partial geometries in this region.

In the method exemplifying the invention, the feature plane forms the interface between the knowledge representation plane and the geometry modelling. It is important for this that the problem solver is capable of the arriving all information items, which are required for a complete description of the geometry, from the feature representation.

Thereby, the method offers the possibility of dynamically defining partial geometries in that namely relationships to other partial geometries are produced. The logic-relational possibilities of description, on which the feature representation in the method exemplifying the invention is based, serve for this purpose. Fig. 5 gives the example for this. It is important that the problem solver is capable of resolving the degrees of freedom, which the feature description can contain, so far that a complete description of the geometry arises.

The possibilties of being able to express different forms of relationships explicitly are of decisive significance for an integration of knowledge processing and geometry modelling. The method exemplifying the invention therefore offers a highly expressive, declarative modelling

of constraints. The following categories of relationships exist:

- Equality conditions between desired objects. This is important for the interface between the logic-relational description on the feature plane and the geometry modelling (compare Fig. 5).
- 'Built-in' relations which express the relationships on and between the different defined planes (for example between generic descriptions and topological instances belonging thereto). These explicitly reflect the modelling possibilities offered for the "actual" geometry by the method exemplifying the invention. The relationships, which exist between the different objects of the geometry modelling, can thereby included explicitly in the problem solving.
- Arithmetic or geometric constraints between geometric parameters (in the form of equalities and inequalities).
- Geometric relations such as "parallel" or "normal".
- User-defined relations such as, for example, the "part" relations between one feature and the features "contained" in it.
- Logical interlinkings between the named "elementary" shapes of constraints.

In order to secure the declarativity of the representations, special methods are required for the treatment of the arithmetic or geometric constraints as well as for the logical relationships. According to the possibilities of these methods, appropriate restrictions in the capability of expression of the constraints are necessary.

The geometrical relationships (such as "parallel", "normal" and so forth) are finally imaged onto the equivalent relationships between the geometric parameters.

User-defined relations as one form of defining relationships between geometric "entities" in the method according to the invention give the modelling a high flexibility. Relationships between geometric entities can be described in a manner which, for example, corresponds with the knowledge in a knowledge base (see, for example, Fig. 5 with an example where the workpiece geometry is described in its components of basic body, x-slot and y-bore. Apart from this possibility of description, it is, however, decisive that the significance, which is intended by the user, of relations of that kind can be expressed by the envisaged modelling. For this purpose, it is required that this significance can be defined. In the case of the method the logical relations, which can be defined between the different forms of constraints, serve for this purpose. Thus, for example, the significance of a relation "connected" between two parallelepipedonal objects can be represented as following:

Connected(X:box, Y:box) → X.x-coord = Y.x-coord
X.y-coord = Y.y-coord + Y.width,
X.z-coord = Y.z-coord,

wherein "→" symbolises the logical implication. As soon as such a connected relation applies between two volumes of the type "box", the co-ordinates of both the objects are "constrained" in the indicated manner.

User-defined relations are in this case also a kind of "macro" for the abbreviated manner of writing for quantities of constraints.

One can, for example, indicate that the base surface of the "slot" and the upper surface of the basic body are to be parallel in the given example of workpiece:

X:workpiece → parallel(X.main-body.top, X.x-slot.bottom).

By a suitable definition of the "parallel" relation between planes (again by a logical interlinking with the geometric parameters of the areas involved), the appropriate constraints are produced between the

geometric parameters.

The advantage of the modelling by the method exemplifying the invention consists in that all relevant relationships between geometric "entities", which can be component of the modelling, can be used in the knowledge representation and represented declaratively as constraints. These possibilities of representation are explicitly available as part of the description language (as a quantity of "built-in" relations).

The method exemplifying the invention is based on a logic-relational geometry representation. Consequently, the individual forms of representation denote either single "entities" or quantities of "entities" according to the significance of the relation. Occasionally, it can be sensible to consider the individual elements or the cardinalship of the quantity of objects denoted by such a relationship: Let "top-inst", for example, be the built-in relationship between a generic surface f and the quantity I of its topological instances in a solid Γ. Then,

$$I = \text{top.inst}\ (f,\Gamma)$$

denotes this relationship. The relationship between this quantity I and its elements can then be represented as following:

$$I = \{\bar{f}_1, \bar{f}_2, \ldots, \bar{f}_n\}$$

When the quantity of the elements is to be represented explicitly and its cardinalship is to be expressed explicitly, this can take place by the following manner of writing the quantities:

$\{\bar{f}_1, \bar{f}_2\} = \text{top-inst}(f,\Gamma)$ expresses that exactly 2 instances exist in the solid Γ,

$\{\bar{f}_1\} = \text{top-inst}(f,\Gamma)$ expresses that exactly one instance exists in the solid Γ and

$\{\} =$ top-inst(f,Γ) expresses that no instances exists in the solid Γ.

For this purpose, it is to be taken into consideration that certain contents of the geometric representation can change non-monotonically by the addition of new geometric information. When thus, for example, a topological instance of a generic area is represented explicitly by a corresponding constraint and this one instance disappears or is divided by further geometry modelling steps, then an infringement of this constraint arises. This signifies a global inconsistency which normally has the consequence of the rejection of the corresponding modelling step.

For the case that the elements of such a quantity are to be denoted, a "member" relation is present in the method exemplifying the invention. With the aid of this, for example, a certain attribute (for example "colour") can be defined for all topological instances f of the named generic surface f:

I = top-inst(f,Γ), F = member(I) $\rightarrow$ F.colour-red.

In detail, the following kind of "built-ins" can be distinguished in the method exemplifying the invention:

a) Direct relationships:

Denoted by this are all those representations which are contained explicitly in the representations, such as for example the original relations, the parts relation and so forth.

b) Derived relationships:

Some geometric relationships are of such significance that built-in relations exist for them although they are not explicitly component of the modelling: for example

Edges = gen-edges (f_1, f_2)

denotes the quantity of all generic edges which form the intersection of both the generic surfaces f_1 and f_2. (In this manner, for example, also the demand could be expressed that two generic surfaces form only one intersecting edge: $\{e_{12}\}$ = gen-edges (f_1, f_2).). Logically, this relation represents the intersection quantity from the "edges" relations of both the participating generic surfaces:

gen-edges (F1, F2) = F1.edges $\cap$ F2.edges.

As diverse as the geometric modelling possibilities are in the method exemplifying the invention, however, not all relationships are describable directly. When, for example, the topological instance $\bar{f}_0$ in a plane f_0 in a geometry model is or is to be a rectangle, this is not expressable directly here. This rectangle arises by the four other planes f_1, f_2, f_3 and f_4, which "cut-out" the rectangle from the generic surface f_0, being represented with the corresponding topological and geometric constraints. This is shown from Fig. 6 for the generic and topological representation of a rectangle (without the associated geometric constraints).

Although this at a first glance has an awkward effect, such a representation - apart from the close conceptional tying-in into the "remaining" scheme of the method exemplifying the invention - offers a series of advantages:

- A priori constraints can be formulated which take care that a certain topology remains maintained (in that it is required also for the topological instance $\bar{f}_0$ that it forms a rectangle with the surfaces f_1, f_2, f_3 and f_4), whereby it is prevented, for example, that

"non-rectangles" as in Fig. 7 arise through further geometric interlinkings.

- It can then be ascertained a posteriori to which class a given topological instance belongs (thus, for example, "rectangle" or "rectangle with circular opening" as in Fig. 7), i.e. a topological classification can take place.

The possibility of the specification of topological constraints is useful in many aspects. Thereby, it can be achieved, for example, that the problem solver causes no changes in the overall geometry, which would lead to inconsistent states. When, for example, a bore is specified as blind bore, it can be prevented thereby that a corresponding topological constraint is specified that the lower boundary surface becomes "cut".

Topological constraints likewise offer the possibility of describing and analysing feature reactions. In that case, two different aspects are concerned:

- On the one hand, feature interactions can be intended: i.e. they are set from the start by the problem solver (or user) in a certain relation one to the other on the feature plane. Topological constraints then offer a possibility of specifying the manner of the interaction exactly (for example, two cylinder surfaces are to cut merely a curve of intersection of fourth order).
- On the other hand, feature interactions arise as a result of the interaction on the geometric plane: They are thus not intended, but also not necessarily prohibited or undesired. From the point of the problem solver, they can even be without significance so that they are treated "merely" by the geometry model maker. They can, however, also be important for the consistency of the overall

geometry so that they must be signalled by the geometric model maker to the problem solver. This interest of the problem solver in such a feature interaction can also be represented by topological constraints.

The addition of new partial geometries (volumes) to an existing geometric model can lead to topological instances, which were hitherto contained in the model, being now no longer such. Since this can be a circumstance which is of significance for the problem solver, the relation "holds" is provided in the method exemplifying the invention, by which relation can be represented whether a certain topological instance $\bar{t}$ (area, edge, point) is contained in the actual solid Γ:

holds ($\bar{t}, \Gamma$) equivalent to $\bar{t}$ is contained in the actual solid Γ.

What makes this relation interesting for the knowledge processing, is its "anti-monotonisity": When $\bar{t} \neg$ holds ($\bar{t}, \Gamma$) applies for a topological instance in a model, this applies also in each model which has arisen therefrom by the addition of new partial geometries.

When thus, for example, a generic surface forms an intersecting edge with another one which has no topological instance, then it also receives none by the addition of further geometry and must thus not even appear also in the representation of the generic edges.

It is often important for the problem solver that certain elements in the overall geometry meet a condition, for example that the length of an edge fulfills a certain constraint. This constraint is to apply independently of changes in the topology which modify also, for example, the end points of this edge. For that reason, it would be sensible to formulate such a constraint as spacing constraint on the end points of the edge, because these are subject to the changes in the topology. The

constraint must be described on the topological edge itself and be adapted in dependence on topological changes.

From the aspect of a knowledge-based system and especially an interactive one, it is a central question to know the dependence between the individual "data", which are component of the just examined or generated solution, and to be able to take them into consideration in the problem solving.

The method exemplifying the invention offers the possibilities for this by the explicit modelling of the different geometric relationships. For each basic volume, for each generic area or edge and for each topological instance, it is unambiguously clear by which geometric features it was "caused". In the case of the revision of a feature by the problem solver, it is thus simple also to revise all geometric entities related thereto. The "constructive" step, which follows thereon, of "repairing" the changes in the overall geometry, which are caused by the disappearance of the one feature, is not quite so simple. Basically, the local geometric operations must be carried out anew at all these places in order to compute the revised overall geometry (inclusive of topology).

In order to achieve the unambiguity between the description on the knowledge plane (the features and their relationships) and the individual geometric "entities", it matters, however, to take an important circumstance into consideration: The monotonisity properties of the geometry. If one assumes that each "action" "x" of the problem solver, which leads to a new feature or a new relation between features and so forth, is represented by a corresponding decision "d_x", then a certain topological instance $\bar{t}$ exists in the entire geometry model by reason of a

certain quantity of decisions of that kind (which represents a partial quantity of all decisions made hitherto by the problem solver):

$$\{d_x, d_y, \ldots, d_z\} \models \text{holds}(\bar{t}, \Gamma).$$

The topological instance can be changed by a further decision d_0 (whereby it is no longer valid in the logical sense): It can drop out entirely from the new overall geometry $\Gamma \otimes \Gamma'$, be modified, be divided, be "melted together" with another topological instance and so forth:

$$\{d_x, d_y, \ldots, d_z, d_0\} \models \neg\text{holds}(\bar{t}, \Gamma \otimes \Gamma') \text{ or}$$
$$\{d_x, d_y, \ldots, d_z, d_0\} \models \neg\text{holds}(\bar{t}, \Gamma \otimes \Gamma'), \text{holds}(\bar{t}', \Gamma \otimes \Gamma') \text{ or}$$
$$\{d_x, d_y, \ldots, d_z, d_0\} \models \neg\text{holds}(\bar{t}, \Gamma \otimes \Gamma'), \text{holds}(\bar{t}_1, \Gamma \otimes \Gamma'),$$
$$\text{holds}(\bar{t}_2, \Gamma \otimes \Gamma') \ \ldots$$

Although holds $(\bar{t}, \Gamma \otimes \Gamma')$ applies in a subquantity $\{dx, dy, \ldots, dz\}$ of the actual decision quantity $\{dx, dy, \ldots, dz, d0\}$, this is no longer the case in the quantity $\{d_x, d_y, \ldots, d_z, d_0\}$, which represents a monotonic enlargement of $\{dx, dy, \ldots, dz\}$.

These relationships cannot be treated in a manner as is otherwise typical for dependency managements (where, it can also be indicated for each subquantity of the decisions, which statements in this quantity are valid) - this is not practicable. A favourable compromise consists in that the overall geometry is represented for each overall quantity of decisions and, therein, for each individual relationship the subquantity of those decisions, which has led to this respective relationship, with respect to the overall quantity of the decisions. When one of the decisions is revised (retracted), it can be stated directly which

geometric relationships thus lose their validity - however, which now apply again must be determined by the new computation of the geometry at the modified places.

CLAIMS

1. A method of computer-aided geometry modelling of a workpiece, comprising the steps of providing an integrated, declarative, sequence-independent and logic-based representation of information relating to volume, areas, edges, point and topology in the form of a representation element composed of individual basic volumes, to each of which a respective density in the form of a positive, zero or negative real number is allocated, interlinking individual representation elements by a commutative and associative interlinking operation, and creating description planes for the respectively relevant information items and their mutual dependence in the form of a volume plane as base plane for the description of elemental structures fixedly preset in composition, a topology plane as representation of the overall geometry, and a generic area plane and a generic edge plane both lying between the volume plane and the topology plane for production of the relationship between the topological structures and the volumes generating those structures.

2. A method as claimed in claim 1, comprising the step of creating an information units plane which lies above the description planes and on which objects are defined in terms of information relating to volume, areas, edges, point and topology with their attributes as well as the relationships and dependencies existing between them in the description planes.

3. A method as claimed in claim 1 or claim 2, wherein a knowledge-based system, which utilises the possibilities of description of geometry and

feature, is used.

4. A method as claimed in any one of the preceding claims, wherein two different types of topological relations exist in the topology plane between areas and edges and between edges and points, wherein one type describes the topology in accustomed manner and the other type expresses that one object influences the topology of another object without itself being influenced.

5. A method as claimed in any one of the preceding claims, wherein geometric models are a priori classified topologically in their description.

6. A method as claimed in any one of the preceding claims, comprising the step of introducing for the topology plane a relation which states whether a specific topological, generic or volume instance is present in an actual geometric model.

7. A method as claimed in any one of the preceding claims, wherein the overall geometry is represented for each overall quantity of decisions and, therein with respect to the overall quantity of the decisions and for each individual relationship, the subquantity of those decisions which has led to this relationship so that, on a change in the decisions, those parts of the geometry are identifiable which are connected with these decisions.

The Patent Office

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Application No:	GB 9705495.1	**Examiner:**	B G Western
Claims searched:	1-7	**Date of search:**	10 June 1997

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G4A AUB

Int Cl (Ed.6): G06F 17/50 ; G06T 17/00 17/10 17/40

Other: On-line databases: COMPUTER, INSPEC, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	US-5272642-A (SUZUKI) See whole document	-
A	Inspec Abstract C91043531 & Biryalcev et al, "STACS 91. 8th Annual Symposium on Theoretical Aspects of Computer Science Proceedings", pub 1991, Springer-Verlag, pp 537-8, "Geometry models design system Gamma POM". See abstract.	-
A	Inspec Abstract C91030793 & You et al, "Proc. Third International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems", pub 1990, ACM, New York, Vol 1, pp 357-64, "Knowledge representation and control structure based on three-dimensional symbolic skeletons for CAD/CAM integration" See abstract.	-

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.